Interim Assessment by Physics Working Groups

- Key questions to address in the physics working groups:
  - What are the main concerns for the proposed experiments to achieve their stated objective?
  - What are the major scientific benefits of the proposed experiments in the physics topical areas?

- For each question, produce clear concise statements on areas of broad agreement and areas of uncertainty or disagreement between the proponents and the physics WGs
  - Tentative conclusions for the report, representing areas of significant agreement
  - Highlight topics that require further discussion in week 2

Physics Working Group Coordinators

Alpha particle physics: Raffi Nazikian, Jim Van Dam

Wave-Particle interactions: Don Batchelor, Miklos Porkalab

MHD physics: Ted Strait, Chris Hegna

Boundary Physics: Gary Porter, Steve Allen

Transport physics: Ron Waltz, Ed Synakowski

Please refer your questions to these lucky individuals

Energetic Particle Physics I:
Issues for accessing proposed operating regime

- Areas of general agreement:

  => Ripple loss well below design limits for all three devices

  - ITER requires ferritic inserts for AT regime

  => ITER is closest to excitation of α-TAEs in its standard regime

  - 1 MeV neutral beams are destabilizing; may lead to fast ion loss and damage to first wall
  - methods for AE suppression may be needed; shape control, edge NBI,…

  => FIRE and IGNITOR are robustly stable to AEs in their standard operating regimes

  - fast ion loss is not likely to be an issue in positive shear

- Areas of large uncertainty:

  => Basic understanding of the physics of AT regimes is still evolving; inadequate for a quantitative assessment

Energetic Particle Physics II:
Issues for accessing proposed operating regime

• Topics requiring further discussion:

=> Role of edge magnetic configuration on mode stability

- effect may be beneficial (stabilizing)

=> Diagnostic capability for measuring alpha parameters;

internal mode structure, fast ion redistribution, loss to wall

=> Effects of alphas on other MHD modes such as KBMs at high beta, Cascade modes in reverse magnetic shear and effect on RWMs

- can these lead to fast ion loss?

• Fast Particle Physics Group needs to meet in week 2 to discuss these issues

=> needs to meet with the diagnostic working group

Energetic Particle Physics III:
What do we want to learn from a BPX?

- First stability reactor (ARIES-I) requires T_0>25 keV, β_0=2.6%
  => Thus a BPX needs the flexibility to explore high temperature alpha dominated AT and normal shear regimes with T_0>25 keV

- Reactor design studies (ARIES-AT, -RS) specify T_0>25 keV in reverse magnetic shear plasmas with β_0>10%

- Areas of general agreement
  => ITER can effectively explore high-n AE stability boundaries with a modest increase in temperature (+20%)
  - i.e., ITER-EDA is unstable at 24 keV

  => FIRE and IGNITOR need to increase temperature by ≈80-100% to explore stability threshold in AT or normal shear

- Topic for discussion in week 2 :
  => Experimental and physics working groups need to meet to discuss high temperature regime accessibility issues in the three devices

Wave-Particle Physics I:
Issues confronting the proposed BPXs

- Areas of general agreement

  => The basic heating mode of all three machines (He^3 minority and second harmonic tritium) is well established from experiment
  - calculations indicate no major heating issues

  => No major issues for LHCD in ITER and FIRE
  - can avoid absorption on alphas by operation at 5 GHz
  - ITER may be underestimating its power requirement

  => No major issues for ECH stabilization of NTMs in ITER
  - need to consider relocating the top side launcher in ITER

  => Scenarios for plasma build up and heating are not well developed for this evaluation

- Areas of large uncertainty:

  => Antenna plasma coupling is poorly understood, needs modeling
  => Basic understanding of LHCD stabilization of NTMs required
  => Absorption of RF waves on alphas requires better modeling

Wave-Particle Interactions II:
What do we want to learn from a BPX?

=> A key area of new science is the interaction of RF waves with a self organized plasma where alpha heating, RF heating, stability and transport are all strongly coupled

- RF plasma control is an open field of investigation in a BPX

=> Reactor studies in reverse and normal shear plasmas require sophisticated MHD and profile control (ARIES-I, -RS, -AT)

• Areas requiring further discussion

=> ITER is the most flexible facility for investigation of RF plasma control. FIRE has less flexibility and IGNITOR has less than the other two.

• Discussion for week 2:

=> Need to resolve the flexibility of the proposed BPXs to methods for RF profile control in regimes of low recirculating power

MHD Physics I:
Issues for accessing proposed operating regime

• Areas of general agreement:

=> MHD stability limits do not present a fundamental obstacle to the burning-plasma missions of the three proposed machines

- Base scenarios are stable to ideal MHD (except m/n=1/1 mode)
- Ignitor operates farther from stability limits due to lower β_N

=> The sawtooth instability is expected in all three devices but are not expected to prevent access to the burning plasma regime

- may trigger NTMs

=> ITER and FIRE will most likely require active control of neoclassical tearing modes (NTMs) to sustain their operating point

- ECH control for ITER is well supported by experiments
- LHCD for FIRE is less well validated as NTM control

MHD Physics II:
Issues for accessing proposed operating regimes

- Areas of general agreement (continued):

=> Error field tolerances required to avoid mode locking during ohmic startup should be achievable in all devices

- ITER and FIRE designs include correction coils
- Ignitor can avoid locking with higher density

=> AT cases in ITER and FIRE need n=1 wall stabilization.

- FIRE can approach the ideal-wall limit with feedback stabilization
- ITER may require a combination of feedback and beam-driven rotation, due to electromagnetic shielding of feedback control coils

- Areas of large uncertainty:

=> Impact of sawteeth on operating regime

- Discusssion for week 2:

=> Need to resolve the worst case impact of sawteeth on the modulation of the fusion power and stored energy of the three burning plasma options

MHD Physics III:
What do we want to learn from a BPX?

- First stability reactor (ARIES I) has positive magnetic shear q(0)>1, may exhibit NTMs

- Second stability reactor designs (ARIES-RS, -AT) will exceed no wall MHD beta limit

- IGNITOR, FIRE, and ITER would all yield important new MHD physics in reactor relevant regimes not accessible in existing devices

=> MHD stability	- with self-heating p(r)
=> sawtooth behavior, NTM seeding	- at large S
=> sawtooth stability (and other modes?)	- with isotropic alphas
=> mode coupling, error field penetration	- with low natural rotation

- FIRE and ITER would address additional issues in H-mode and high β_N

=> NTM threshold beta, pedestal stability	- with small $\rho^*=\rho_i/a$

- Advanced tokamak regimes in FIRE and ITER yield additional physics

=> MHD stability	- with largely self-generated current profile
=> RWM stabilization	- with low natural rotation

Boundary Physics I:
Issues for accessing proposed operating regime

• Areas of general agreement:

=> Estimates of power loads in divertor or limiter are consistent with figures obtained from the advocates. Concerns exist, but they are not clear show stoppers.

=> ELM power loads on ITER and FIRE are on the upper boundary of acceptable energy deposition. ELM control and amelioration may be needed.

=> Tritium retention is a major concern on the proposed ITER carbon divertor. No validated solution exists. Problem may limit long term operation. Metal limiter or divertor should avoid this problem.

=> The current IGNITOR does not plan to pump plasma exhaust, hence cannot address He ash removal

• Areas of large uncertainty:

=> Compatibility of high-Z metals in high heat load regions with low plasma impurity.

Boundary Physics II:
Issues for accessing proposed operating regime

• Areas requiring further discussion in week 2:

=> Compatibility of limiter operation with core plasma confinement in IGNITOR

- Interaction between technology (PFCs), Physics (Boundary and confinement -P4/E2)

=> Trade off between tritium retention and metal PFCs in high heat flux regions.

- Interaction between technology (PFCs) and physics (Boundary)

=> Special session on ELM and pedestal physics involves MHD, transport and Boundary groups.

Boundary Physics III:
What do we want to learn from a BPX?

=> A BPX will allow the study of core-edge integration and power exhaust in reactor relevant regimes

- operates at higher n/n_{GW} for the same collisionality making detached edge operation more accessible at higher density
- SOL and pedestal scaling at reactor relevant collisionality and impact on PFCs

=> Investigate particle control and fueling (eg helium pumping) in a BPX

- FIRE and ITER have pumping sufficient to address this issue

=> Investigate the compatibility of metals in high heat load regions (10-40 MW/m^2) expected in a BPX.

- core impurity control with metal PFCs
- Tritium retention

Transport Physics I:
Issues for accessing proposed operating regime

• Areas of general agreement:

=> Applying standard empirical H-mode confinement time and power access rules, all three devices can achieve their performance goals of dominant alpha self-heating.

- ITER and FIRE with standard diverter operation are designed for H-mode access at full parameters.

- IGNITOR is not designed for H-mode, but a de-rated current "wall-separatrix" operation may well access H-mode confinement

• duration possibly limited by power handling

=> Dominant alpha self-heating in the proposed low temperature edge wall limiter operation in IGNITOR requires ≈1.5x enhancement of standard L-mode confinement which may be achieved by density peaking.

Transport Physics II:
Issues for accessing proposed operating regime

• Areas of large uncertainty:

=> Fusion gain is a sensitive parameter and difficult to predict accurately. Typically a predicted Q of 10 has an uncertainty 5<Q<15, corresponding to 50 -75% alpha self-heating [F=Q/(5+Q)]. If Q's in this range can be obtained at full auxillary power, *"ignition" (nearly infinite Q and 100% self-heating) is not precluded at reduced power according to model analysis.*

• Topic for discussion in week 2 :

=> Need further discussion of H-mode pedestal height rules and relative stiffness of core confinement particularly with respect to power scaling.

=> Need further discussion on the experimental and theoretical basis for enhancement over L-mode confinement time scaling consistent with a cold edge plasma.

Transport Physics III:
What do we want to learn from a BPX?

=> Non-linear coupling between alpha heating, flows and MHD equilibrium in self heated regime

=> pedestal characteristics and global confinement at small ρ^* and collisionality

=> electron thermal transport (high-k instabilities) and global confinement in alpha dominated regime

- Topic for discussion in week 2 :

  => Flexibility of the proposed devices for AT access and control

  - ITER is the most flexible device (CD, heating, NBI) for plasma control
  - FIRE plans significant CD and heating capability, NBI for rotation not planned
  - IGNITOR pressure control outside mission of the device. AT access at low beta is possible at reduced parameters

  => Discussion with diagnostics working group needed for assessment of critical transport and fluctuation measurement needs

Monday Afternoon

4:30 to 6:00	Pedestal and ELMs	Synakowski et al.,

Scheduled Tuesday physics WG meetings

Morning

8:30 to ?	m = 1 modes	Hegna, Strait
8:30 to ?	wave-particle	Batchelor, Porkolab
8:30 to ?	temperature flexibility	Nazikian,
8:30 to ?	transport projections	Waltz, E2
8:30 to 10:30	boundary/technology	Porter, Tech. WG rep.
10:30 to 12:00	transport diagnostics	Synakowski, Diag. rep.

Afternoon

1:30 to ?	boundary/transport	Porter, Waltz
1:30 to ?	fast ion diagnostics	Boivin, Nazikian
1:30 to ?	AT access and control	Synakowski, Porkolab

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